University of Hamburg, Department of Physics

Nonlinear Optics

Kärtner/Mücke, WiSe 2018/2019

Problem Set 9

Issued: 21.12.18 Due : 11.01.19

1. Electro-Optic Sampling

Electro-optic sampling (EOS) allows to measure signals with frequencies ranging from the micowave to the terahertz region in real time. The figure below shows an integrated microwave GaAs-strip line. In those GaAs integrated circuits, transient electric signals can be measured by use of short ps to fs laser pulses.

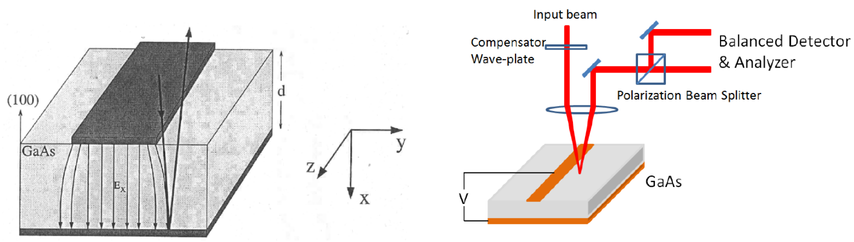

Figure 1: Sketch of the EOS setup with indicated beam path.

A microstrip line is sputtered on a GaAs substrate which is metalized on its back. The thickness of the substrate is $d = 100\mu m$ and so is the distance between the conductors. A high frequency signal that propagates along the strip-line can then be sampled with fs laser pulses. The laser is focused close to the strip and reflected back from the metalized back surface. A polarization compensator plate (waveplate) is used at the input to tune the range of electric field detection to be in a linear regime. The polarization of the reflected beam is detected and allows to retrieve the electric field the optical pulse has sampled. Use the only non-zero element of the electro-optic tensor $r_{41} = 1.43\frac{pm}{V}$ and the refractive index $n = 3.43$ for GaAs.

(a) Assume the laser beam propagates along the x direction and is polarized along the y direction. Calculate the birefringence induced by the voltage $V_x = E_x \cdot d$ across the strip-line and find an expression for the change of the polarization state of the reflected beam as a function of the voltage V_x. Start with the index ellipsoid under an externally applied electric field E_x and then derive the new main axes and the phase difference $\Delta\Phi$ between polarization states along these after propagation through the material. Helpful information to get you started can be found in: B.H. Kolner and D.M.Bloom,"Electro-optic sampling in GaAs integrated circuits", IEEE J.Quantum Electron. QE-22, 79(1986).

Hint: You should arrive at $\Delta\Phi = \frac{4\pi}{\lambda} r_{41} n^3 V_x$.

(b) Assume your polarizer before your detector only lets the z-component of the laser field pass. Show that the transmission $T = \frac{I_{in}}{I_{out}}$ through the setup then can be written as $T = E_0^2 \sin^2(\frac{\alpha}{2} + \frac{\Delta\Phi(V_x)}{2})$, where E_0 is the initial amplitude of the laser field and α denotes the polarization retardation by the polarization compensator. Explain in your own words what the purpose of the polarization compensator is! Derive the change in the polarization state that should be added by the polarization compensator in order to have an output signal from the reflected beam that changes approximately linear with the voltage across the strip-line. What type of waveplate should be used?.

(c) Imagine we can measure a change of 10^{-5} in transmission. What will be the lowest voltage V_x you could still measure? Assume you are using a laser at wavelength $\lambda = 1060nm$.